

Optimization Studies on Surface Grinding Process Parameters

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ABSTRACT: In the manufacturing sector, producing smooth surface finish plays an important role. To fulfill this smooth finish, surface grinding process is mostly used in which the parameters to be considered are surface quality and metal removal rate. Several factors which include depth of cut, wheel grade, wheel speed, material properties and table speed affects the machining process economics. This paper mainly focuses on developing the empirical models using response surface methodology for surface roughness and metal removal rate by considering control factors as wheel speed, table speed and depth of cut. The main objective of using Response surface methodology (RSM) on surface grinding operation of EN8 steel is to find optimum machining parameters which leads to minimize surface roughness and maximum metal removal rate. For metal removal rates (MRR) and Surface roughness, second order mathematical models were developed based on experimental results and the models are validated with F-test. Analysis of variance (ANNOVA) method was used to find the adequacy of the models based on their output responses. This paper makes an attempt in optimizing cutting parameters with the help of RSM using multi objective characteristics for the models.

KEYWORDS: Surface grinding, RSM, F-test, MRR, Optimization, Surface roughness.

I. INTRODUCTION

Grinding is a metal removing process performed with the help of grinding wheel. It is employed for finishing various parts such as engine crank-shafts, splined shaft, lathe guide ways, long pipes, worms, toothed gears, pinions, racks and surfaces. Surface grinding is the process of producing flat surfaces by means of revolving abrasive wheel. According to the shape of the table and its movement, surface grinding machines can be divided into two categories – planer type and rotary type. In planner-type surface grinders, the table is rectangular in shape and traverses under the wheel. In rotary – type surface grinders, the table is circular in shape and rotates under the wheel. According to the position of the spindle, surface grinder can also be classified as a) horizontal spindle and b) vertical spindle. The various parameters which influence the surface quality in surface grinding process are wheel parameters, work piece parameters, process parameters and machine parameters [1]. These parameters must be properly selected in order to obtain desired surface finish and MRR [2].

The present work involves the development of second order mathematical models using Response surface methodology and Design of Experiments in order to predict surface roughness and metal removal rate. Analysis of variance is employed to check and validates the models. Design of Experiments (DOE) mainly focuses on the impact of variables which influence the quality of the product.

II. MATERIALS AND METHODOS

The material chosen for this work was EN8 steel as it suits engineering applications that need steel of superior strength and it contains less carbon. It is widely used in areas like general engineering, fabrication jobs, grating industries, component manufacturing and so on. A rectangular plate of dimensions 300mm x 200mm x 20mm was taken and it was machined using CNC surface grinding machine for obtaining results.

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The present work involves the use of Response surface methodology (RSM) method as it is accurate, practical and easy for implementation. The method starts with conducting experiments and obtaining values. Then these experimental values were used to formulate second order mathematical models using regression analysis method. RSM procedure was implemented on those mathematical models for optimization in which the output responses were analyzed by various input machining parameters such as table speed, wheel speed and depth of cut.

DESIGN OF EXPERIMENTS (DOE)

To use the statistical approach in designing and analyzing an experiment, it is necessary for everyone involved in the experiment to have a clear idea in exactly what is to be studied, how the data are collected, and at least a qualitative understanding of how these data are to be analyzed.

Designing experiments for following steps

1. Recognition of statement of the problem.
2. Choice of factors, levels, and ranges.
3. Selection of the response variable.
4. Choice of experimental design. example L9, L18,L27 etc.
5. Performing the experiment.
6. Statistical analysis of the data.
7. Conclusions and recommendations.

RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology (RSM) consists of a group of mathematical and statistical Techniques used in the development of an adequate functional relationship between a response of interest, y , and a number of associated control (or input) variables denoted by x_1, x_2, \dots, x_k .

The response surface methodology follows the main steps

1. Identification of controllable factors the influence the output responses such as Surface roughness, material removal rate.
2. The above data used to design the experimental matrix and conduct the experimental trails.
3. Mathematical models can be develop by using above data.
4. Predict the constant coefficients for model
5. Checking the developed model coefficients significance or not.
6. After significance ANNOVA technique used to test the developed model.
7. Influencing input parameters on surface roughness and material removal rate can be analyzed.

III. MATHEMATICAL FORMULATION

Multiple regression analysis used to develop the first order and second order models for surface roughness and material removal rate. Multiple regression models are related to optimized values of output responses based on the input factors.

The mathematical models can be represented like that

$$Y = f(A, B, C) \quad (1)$$

Where,

Y is output response, A is Wheel speed, B is table speed, and C is depth of cut.

The responses formulated in the mathematical models.

$$\text{Material removal rate} = K_1 A^{a_1} B^{b_1} C^{c_1} e \quad (2)$$

$$\text{Surface roughness} = K_2 A^{a_2} B^{b_2} C^{c_2} e \quad (3)$$

Where,

K_1, K_2 are constants and e is exponent

The logarithmic transformation can be performed in the mathematical model to linearised as follows

$$\ln \text{MRR} = \ln K_1 + \ln A^{a_1} + \ln B^{b_1} + \ln C^{c_1} e \quad (4)$$

$$\ln \text{Rs} = \ln K_2 + \ln A^{a_2} + \ln B^{b_2} + \ln C^{c_2} e \quad (5)$$

Functional relationships used to develop the models

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$$y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \epsilon \tag{6}$$

$$y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i < j} \beta_{ij} x_i x_j + \sum_{i=1}^k \beta_{ii} x_i^2 + \epsilon. \tag{7}$$

Before going to optimization the models were tested in the F-test and Chi-square test.

IV. EXPERIMENT DETAILS

Several experiments were conducted on surface grinding machine in order to verify whether the output parameters such as surface roughness and metal removal rates varies or not with input machine parameters such as table speed, wheel speed and depth of cut. The specifications of machine and the material were as given in below table I. here the grinding wheel used was made of aluminium oxide abrasives with vetrified bond, AA 46/54K5V8. Table II was level of independent control factors. Orthogonal array was designed with the help of Design of Experiments (DOE) using three factors and three levels. The orthogonal array selected to conduct the experiments was L27 as shown in below table III. MRR was calculated as the ratio of volume material removed from the work piece to the machining time. The surface roughness, Ra was measured in perpendicular to the cutting direction using Surface Roughness tester SJ-201 at 0.8mm cutoff value. To evaluate the output response of surface roughness, six values were obtained and are averaged. These results will be used further to analyze the effect of input machining parameters on output responses with the help of RSM and DESIGN EXPERT V7.1.3 software.

TABLE I
MACHINING CONDITIONS

a) Work piece material: EN 8 steel
b) Chemical composition: Carbon 0.35-0.45, Silicon 0.10-0.35, Manganese 0.45-0.70, Sulphur 0.060 (max)/ Phosphorous 0.060(max) and balance Fe
c) Work piece dimensions: 300mm x 20mm x 20mm
d) Physical properties: Hardness-201 brinell, Tensile Strength-620 Mpa
e) Grinding wheel: Aluminum oxide abrasives with vitrified bond wheel AA46/54 K5V8
f) Grinding wheel size :180 mm OD x13 mm width x 31.75 mm ID

TABLE II
LEVELS OF INDEPENDENT CONTROL FACTORS

S. No	Control Factor	Symbol	Level of factors			Unit
			-1	0	+1	
1	Wheel speed	A	1250	1650	2050	RPM
2	Table speed	B	7.5	10	12.5	m/min
3	Depth of cut	C	5	10	15	µm

TABLE III
EXPERIMENTAL OBSERVATIONS

Trail no	Wheel speed (A)(RPM)	Table speed (B)(m/min)	Depth of cut (C)(µm)	Surface Roughness (Rs)(µm)	Metal Removal rate MRR(gm/min)
1	1250	7.50	5	1.034	5.510
2	1250	7.50	10	1.440	10.28

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3	1250	7.50	15	1.624	15.505
4	1250	10.0	5	1.324	7.350
5	1250	10.0	10	1.591	13.28
6	1250	10.0	15	1.721	22.07
7	1250	12.5	5	1.38	9.190
8	1250	12.5	10	1.679	16.89
9	1250	12.5	15	1.940	26.09
10	1650	7.50	5	1.180	6.260
11	1650	7.50	10	1.56	13.13
12	1650	7.50	15	1.684	17.68
13	1650	10.0	5	1.490	11.63
14	1650	10.0	10	1.641	15.61
15	1650	10.0	15	1.716	21.70
16	1650	12.5	5	1.501	12.42
17	1650	12.5	10	1.691	18.17
18	1650	12.5	15	1.826	25.87
19	2050	7.50	5	1.361	7.760
20	2050	7.50	10	1.582	13.21
21	2050	7.50	15	1.703	19.40
22	2050	10.0	5	1.460	10.35
23	2050	10.0	10	1.632	15.16
24	2050	10.0	15	1.805	24.16
25	2050	12.5	5	1.513	12.64
26	2050	12.5	10	1.734	22.44
27	2050	12.5	15	2.072	30.44

V. DEVELOPMENT OF EMPIRICAL MODELS

The relationship between the input factors and output responses used to develop the empirical models. After machining parameter optimization the empirical models can be used. The DESIGN EXPERT V7.1.3 software used to develop the second order models for the output responses. The obtained actual factors equations for surface roughness and material removal rate.

$$\text{Surface roughness} = -0.43936 + 4.52743E-004 * \text{wheelspeed} + 0.12451 * \text{tablesfeed} + 0.096960 * \text{depthofcut} - 1.90000E-005 * \text{wheelspeed} * \text{tablesfeed} - 1.25417E-005 * \text{wheelspeed} * \text{depthofcut} + 5.33333E-005 * \text{tablesfeed} * \text{depthofcut} + 5.90278E-009 * \text{wheelspeed}^2 - 2.27556E-003 * \text{tablesfeed}^2 - 1.70222E-003 * \text{depthofcut}^2$$

$$\text{MRR} = -2.70909 + 3.52274E-003 * \text{wheelspeed} - 0.18759 * \text{tablesfeed} - 0.21802 * \text{depthofcut} + 3.56250E-004 * \text{wheelspeed} * \text{tablesfeed} + 6.81250E-005 * \text{wheelspeed} * \text{depthofcut} + 0.10063 * \text{tablesfeed} * \text{depthofcut} - 1.11632E-006 * \text{wheelspeed}^2 + 2.35556E-003 * \text{tablesfeed}^2 + 0.021522 * \text{depthofcut}^2$$

The level of significance can be tested by using the analysis of variance (ANOVA). The surface roughness and material removal rate can be found in second order models were 0.9321 and 0.9796 respectively. The "Pred R-Squared" of 0.8017 is in reasonable agreement with the "Adj R-Squared" of 0.8961 in case of surface roughness. The "Pred R-Squared" of 0.9524 is not as close to the "Adj R-Squared" of 0.9684 as one might normally expect in MRR. F-values for surface roughness and material removal rate are 25.91 and 89.53 is significant. And also S/N ratio of the output responses are 18.350 and 33.447. The surface roughness and material removal rate ANOVA models for Response quadratic models as shown in below Tables IV and Table V.

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TABLE IV
ANOVA FOR RESPONSE SURFACE QUADRATIC MODEL OF SURFACE ROUGHNESS

Source	Sum of Squares	Df	Mean Square	F Value	pvalueProb >F significant
Model	1.18	9	0.13	25.91	< 0.0001
A-wheelspeed	0.071	1	0.071	14.01	0.0016
B-tablespeed	0.26	1	0.26	51.67	< 0.0001
C-depthofcut	0.82	1	0.82	162.78	< 0.0001
AB	4.332E-003	1	4.332E-003	0.86	0.3675
AC	7.550E-003	1	7.550E-003	1.49	0.2383
BC	5.333E-006	1	5.333E-006	1.055E-003	0.9745
A ²	5.352E-006	1	5.352E-006	1.059E-003	0.9744
B ²	1.214E-003	1	1.214E-003	0.24	0.6304
C ²	0.011	1	0.011	2.15	0.1608
Residual	0.086	17	5.054E-003		
Cor Total	1.26	26			
Std. Dev.	0.071		R-Squared	0.9321	
Mean	1.59		Adj R-Squared	0.8961	
C.V. %	4.48		Pred R-Squared	0.8017	
PRESS	0.25		Adeq Precision	18.350	

TABLE V
ANOVA FOR RESPONSE SURFACE QUADRATIC MODEL OF MATERIAL REMOVAL RATE

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	1105.80	9	122.87	89.53	<0.0001 significant
A-wheelspeed	48.00	1	48.00	34.98	< 0.0001
B-tablespeed	237.73	1	237.73	173.22	< 0.0001
C-depthofcut	797.40	1	797.40	581.02	< 0.0001
AB	1.52	1	1.52	1.11	0.3069
AC	0.22	1	0.22	0.16	0.6921
BC	18.99	1	18.99	13.84	0.0017
A ²	0.19	1	0.19	0.14	0.7134
B ²	1.300E-003	1	1.300E-003	9.476E-004	0.9758
C ²	1.74	1	1.74	1.27	0.2762
Residual	23.33	17	1.37		
Cor Total	1129.13	26			
Std. Dev.	1.17		R-Squared		0.9793
Mean	15.71		Adj R-Squared		0.9684
C.V. %	7.46		PredR-Squared		0.9524
PRESS	53.80		AdeqPrecision		33.447

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Normal probability of residuals of responses for surface roughness and material removal rate were plotted using RSM software as shown below in fig 1.

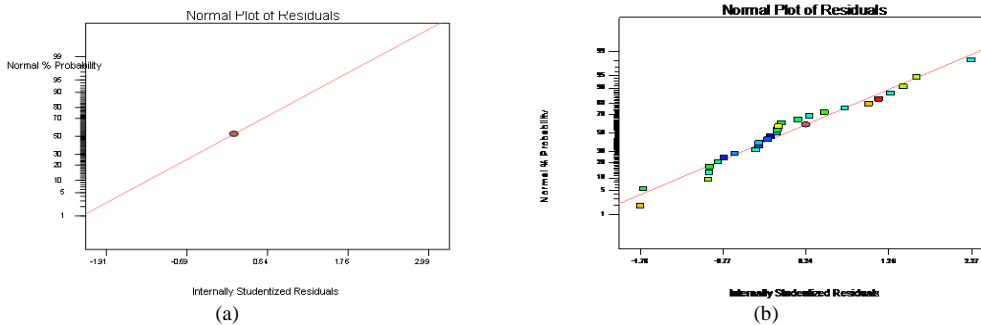


Fig.1. Normal probability of residuals of responses (a) Surface roughness (b) Material removal rate

Predicted and actual values of surface roughness and material removal rate were plotted using RSM software as shown below in fig 2.

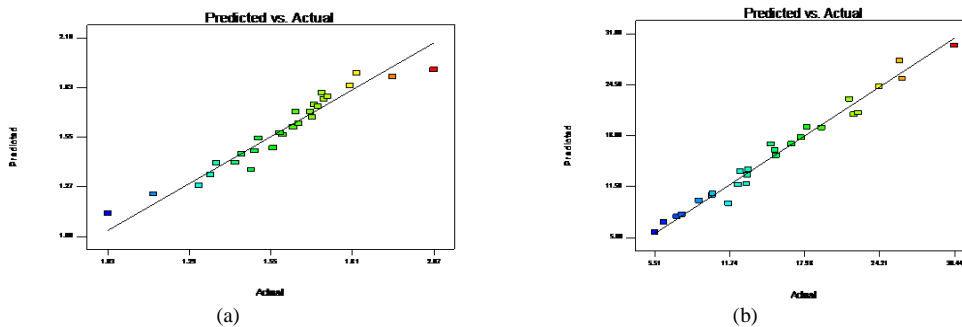


Fig.2. Predicted and actual values of responses (a) Surface roughness (b) Material removal rate

VI. INTERPRETATION OF DEVELOPED MODEL

Effects of process parameters on Surface roughness:

The input parameters direct and interaction effects on output response1

Direct effects:

In the below fig.3. shows the direct effects of wheel speed, table speed and depth of cut on surface roughness. Fig.3. (a) shows that when the wheel speed increases reduce the surface roughness, (b) is shows the table speed effects on surface roughness when the table speed is faster the finishing is reduced then tool marks are shows on the work piece and (c) is shows depth of cut reduced surface roughness also reduced. Compare the all direct effects minimum surface roughness in smaller table speed , depth of cut and larger wheel speed.

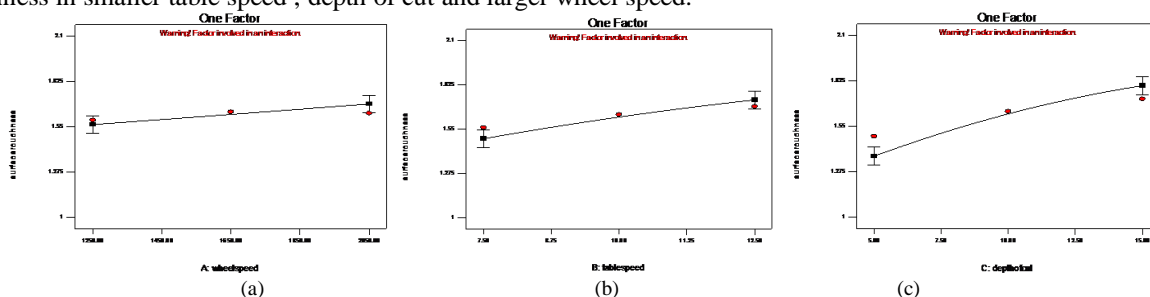


Fig.3. Direct effects of input factors on surface roughness (a) Wheel speed effects (b) Table speed effects (c) Depth of cut effects

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Interaction effects on Surface roughness:

The three input parameters interaction effects on surface roughness shown on the 3D surface plots in fig 4. In each surface plots two control factors considered. Fig.4. (a)shows the good surface roughness in low table speed and medium wheel speed. (b) is shows the poor surface finish in low depth of cut and low wheel speed and also shown the non linearity in the graph . And in the (c) is shown the low depth of cut and low table speed improve the surface roughness.

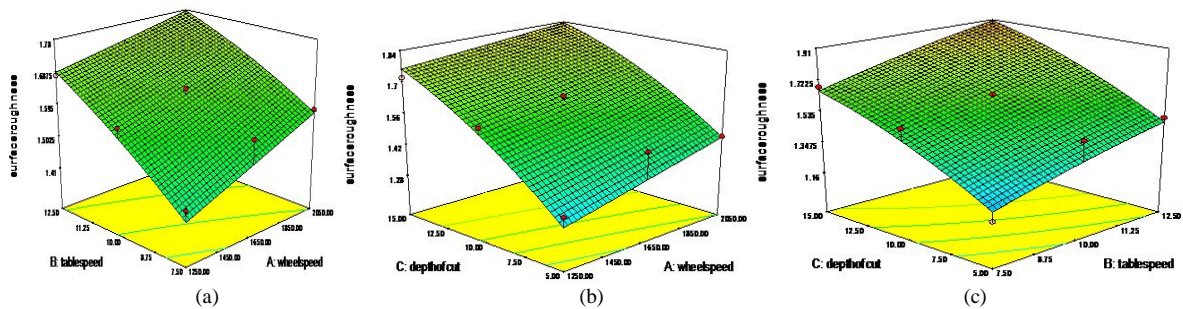


Fig.4. Interaction effects on surface roughness (a) wheel speed and table speed,(b) wheel speed and depth of cut, and(c)table speed and depth of cut

Effects of Input parameters on Material removal rate:

Direct effects

In the below Fig.5. shows the direct effect of input parameters on the material removal rate. Fig.5. (a) shown the wheel speed effect on MRR wheel speed ,where an additional parameters set aside in to mid value. (b) is shows the Depth of cut based material removal rate in high depth of remove high material. And in Fig.5.(c) is shows the table speed effects when the table speed increases improve the material removal rate. In the direct effects high range of material is removed all parameters are extreme range.

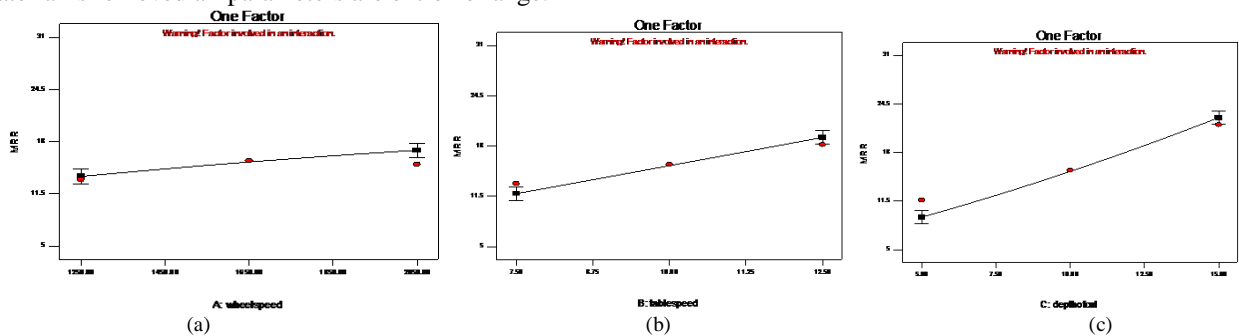


Fig.3.Direct effects of input factors on material removal rate (a)Wheel speed effects (b)Table speed effects(c) Depth of cut

Interaction effects of material removal rate

The three input parameters interaction effects on surface roughness shown on the 3D surface plots in Fig.6 shows the curvilinear profile as empirical model developed is quadratic. In each surface plots two control factors considered and another factor is kept middle value. From Fig.6. (a) shows the max wheel speed and medium table speed improve the material removal rate. (b) is shows the non linearity in the graph with low wheel speed and depth of cut then plugging action takes place tool on the work piece in low depth of cut. And (c) is shows the medium depth of cut and medium table speed improve the material removal rate.

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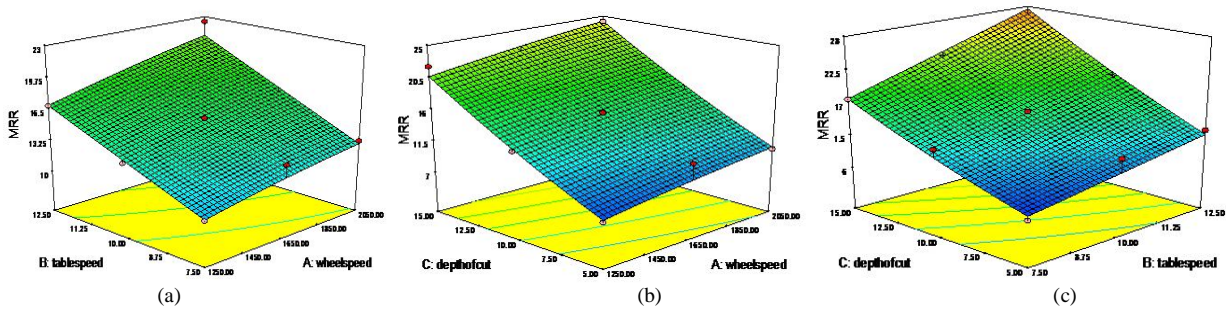


Fig.6. Interaction effects on surface roughness (a) wheel speed and table speed,(b) wheel speed and depth of cut and(c)table speed and depth of cut

VII. FORMULATION OF PROBLEM

In the process parameter optimization process, the main objective is to reduce the surface roughness and increase the material removal rate, which forms the multi objective optimization. The generated empirical model equations as given below are used.

Minimize

$$\text{Surface roughness} = -0.43936 + 4.52743E-004 * \text{wheelspeed} + 0.12451 * \text{tablespeed} + 0.096960 * \text{depthofcut} - 1.90000E-005 * \text{wheelspeed} * \text{tablespeed} - 1.25417E-005 * \text{wheelspeed} * \text{depthofcut} + 5.33333E-005 * \text{tablespeed} * \text{depthofcut} + 5.90278E-009 * \text{wheelspeed}^2 - 2.27556E-003 * \text{tablespeed}^2 - 1.70222E-003 * \text{depthofcut}^2$$

Maximize

$$\text{MRR} = -2.70909 + 3.52274E-003 * \text{wheelspeed} - 0.18759 * \text{tablespeed} - 0.21802 * \text{depthofcut} + 3.56250E-004 * \text{wheelspeed} * \text{tablespeed} + 6.81250E-005 * \text{wheelspeed} * \text{depthofcut} + 0.10063 * \text{tablespeed} * \text{depthofcut} - 1.11632E-006 * \text{wheelspeed}^2 + 2.35556E-003 * \text{tablespeed}^2 + 0.021522 * \text{depthofcut}^2$$

Subject to

$$1250 \text{ RPM} \leq A \leq 2050 \text{ RPM}$$

$$7.5 \text{ m/min} \leq B \leq 12.5 \text{ m/min}$$

$$5 \mu\text{m} \leq C \leq 15 \mu\text{m}$$

Once the optimization of problem generated, then it was solved by using the response surface methodology.

VIII. OPTIMIZATION OF PROBLEM

Optimization of process parameters increases the effectiveness of the machining finances, a RSM is attempted using DESIGN EXPERT V7.1.3 software. The optimum results are show in the Table6.

TABLE VI
RSM OPTIMIZATION FOR OUTPUT RESPONSES

RESPONSES	Objective function	Optimum values			Predicted response	Expected value	% of error
		A	B	C			
Surface roughness RS	Min	1250	7.5	5	1.1293	1.034	8.4
MRR	Max	2050	12.5	15	29.3	30.44	4.2

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IX. RESULTS

The optimum results for the output responses namely surface roughness and Metal removal rate in terms of machining parameters namely wheel speed, table speed and depth of cut on EN 8 steel on CNC surface grinding machine using DESIGN OF EXPERT V7.1.3 software were determined and presented in Table 6. From the results it can be observed that there is not much error between the experimental values and predicted values and that error is about 4 to 8 %. Thus the response optimization predicts the optimum conditions fairly well.

X. CONCLUSION

In this work an experimental investigation is carried out to predict the surface roughness and MRR parameters of EN 8 steel in surface grinding operation. The output responses considered for evaluating the results which are influenced by input parameters such as cutting speed, feed rate and depth of cut were obtained from the experiments and these were optimized using Response surface methodology. The empirical models of output parameters are established and tested through the analysis of variance to validate the adequacy of the models. It is found that the surface roughness and MRR parameters greatly depend on work piece materials. A response surface optimization is attempted using DESIGN OF EXPERT V7.1.3 software for output responses in surface grinding.

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